Performance Challenges for Simulation of Turbulent Flows in Complex Geometries

Danesh Tafti

dtafti@vt.edu

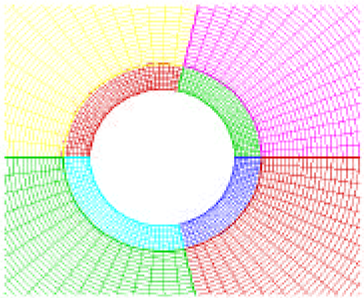
(540)231-9975

Large-Eddy Simulations (LES)

- **Solve unsteady Navier-Stokes and energy equation by resolving all scales of turbulence up to the inertial range *on the computational mesh* ($N \propto \mathrm{Re}^2$)**
  - **turbulent length and time scales now decided explicitly by the mesh ~ *dx.***
  - **Scales smaller then *dx* are not included and have to be modeled - subgrid stress modeling**
  - **Captures relevant turbulent physics with good fidelity - but compute intensive**
  - **Also data intensive**

Alliance Funding

- **Development and deployment of GenIDLEST**
- **General Incompressible Direct and Large-Eddy Simulations of Turbulence**
  - **Boundary conforming transformations**
  - **Multi-block structured grid**
  - **Unstructured block topology**
    - **x-direction boundary can interface with h- or z-direction boundary with arbitrary axes orientations**
  - **Non-matching block interfaces**
    - **Allows zonal embedding and flexibility in meshing complex geometries**
  - **Distributed/shared memory parallel computing technology**



Current Applications

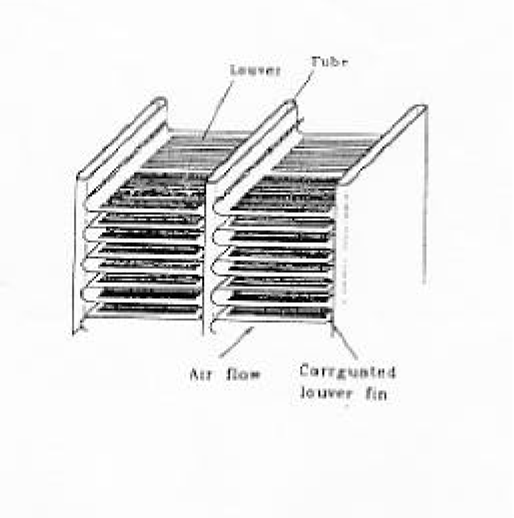
- Air-side heat transfer enhancement in compact heat exchangers
- Turbomachinery – internal/film cooling and combustors
- Process Equipment
- Microflows: lab-on-a-chip applications

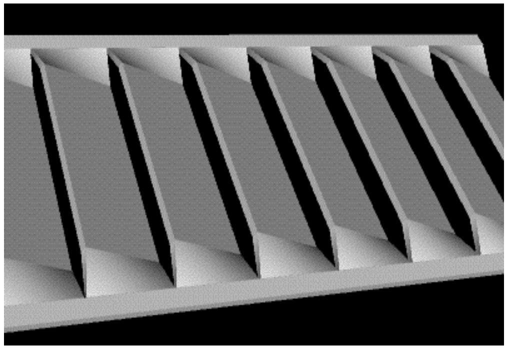
Other Users:

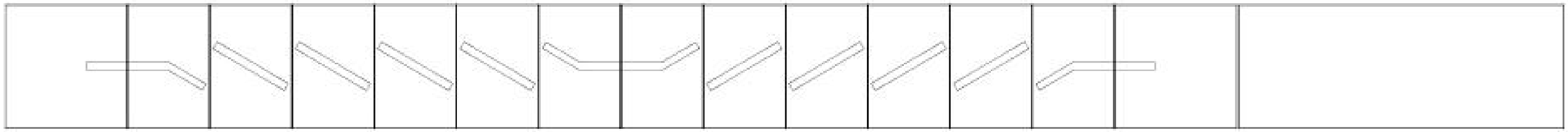
Shell Oil

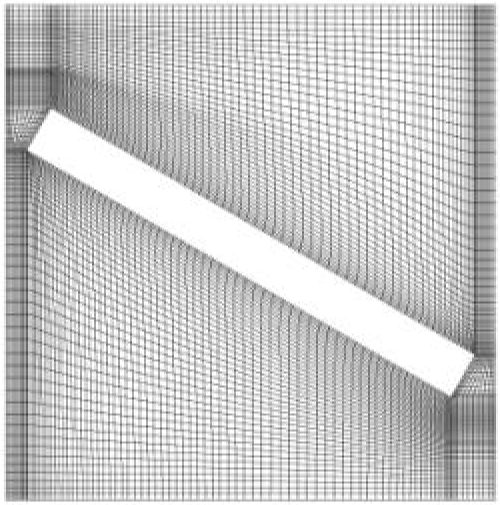
Virginia Active Combustion Control Group (VACCG)

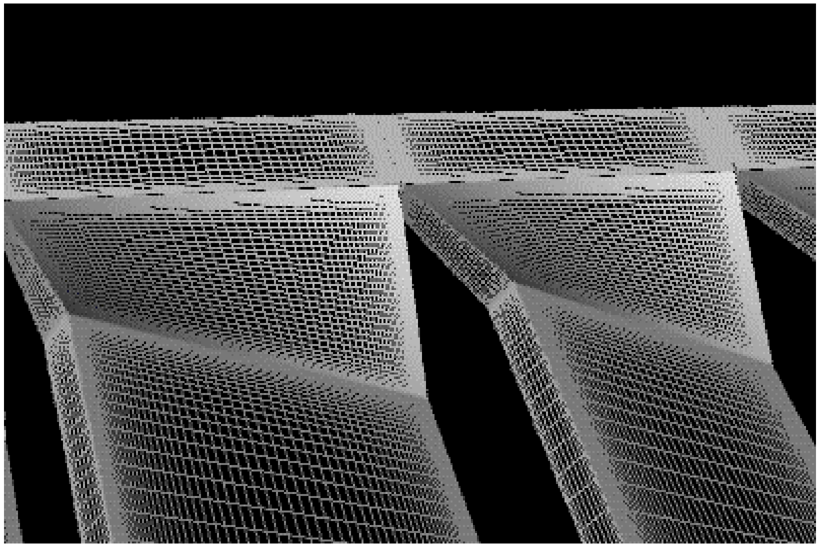
Compact Heat Exchangers - Industry





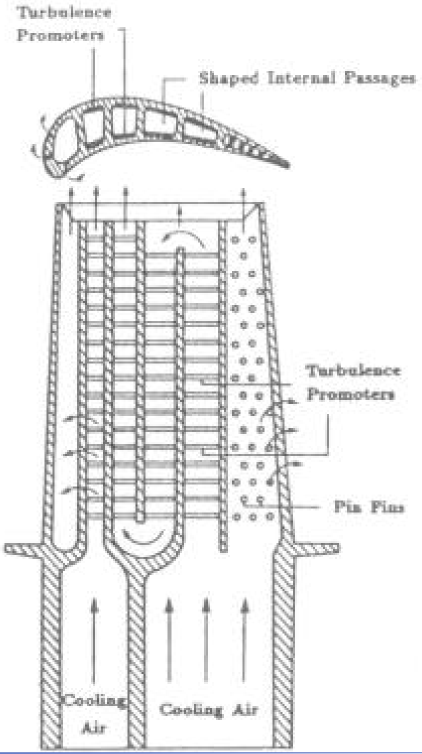


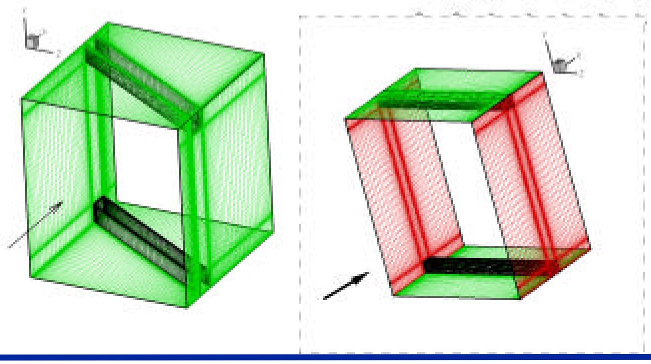


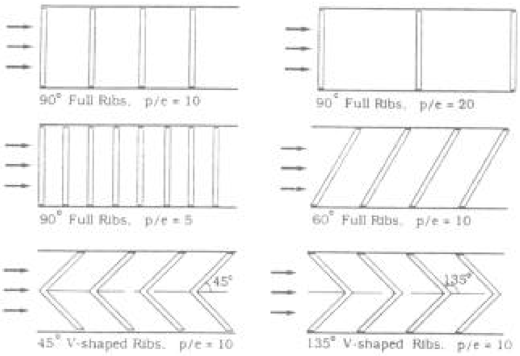


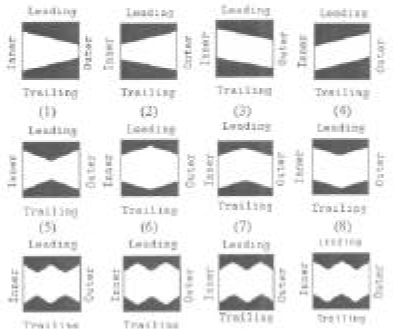
Internal Turbine Blade Cooling – DOE/industry

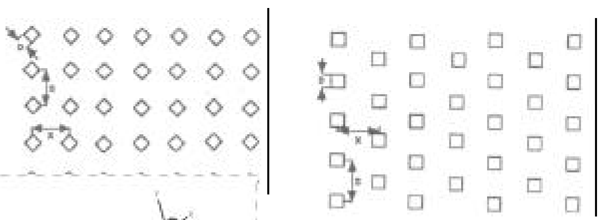
- **Flow is unsteady and turbulent, Re ~ 20 - 50,000.**
  - square, rectangular or trapezoidal channels
  - augmentation through ribs - roughness elements

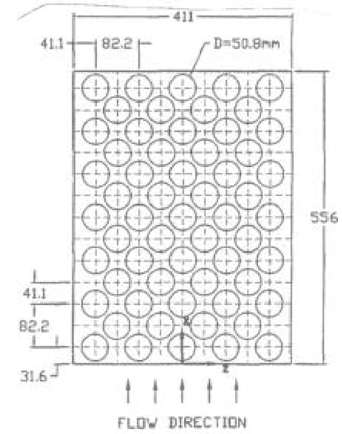




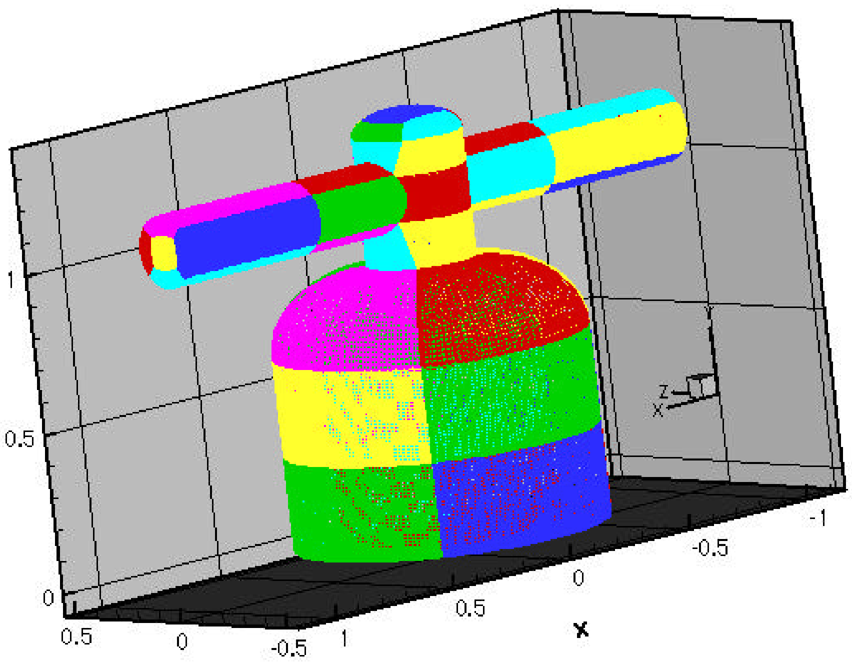


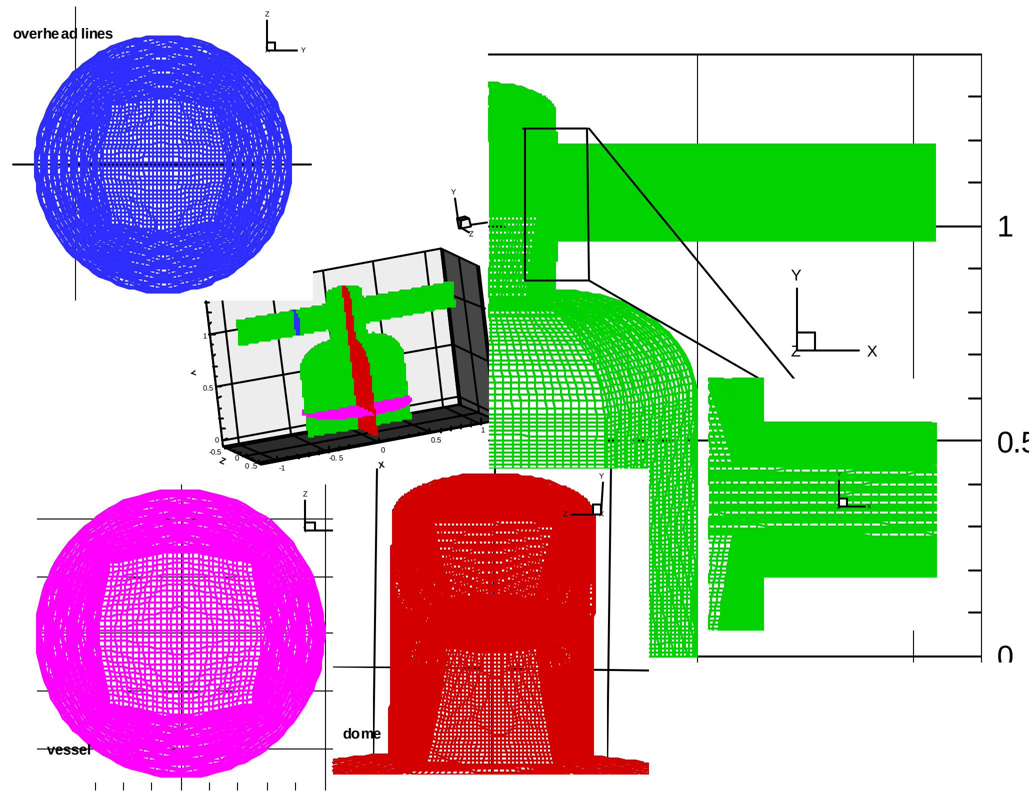


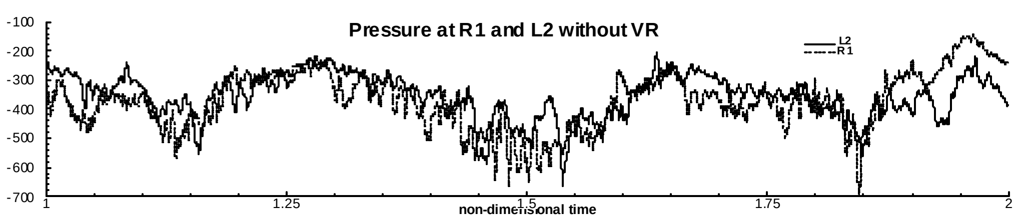


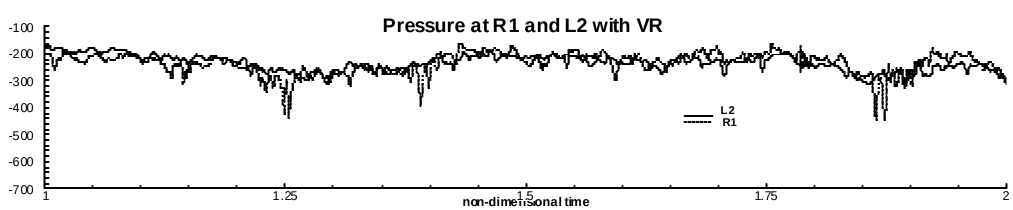


Flow Induced Vibrations in a Flasher Unit – Shell Oil





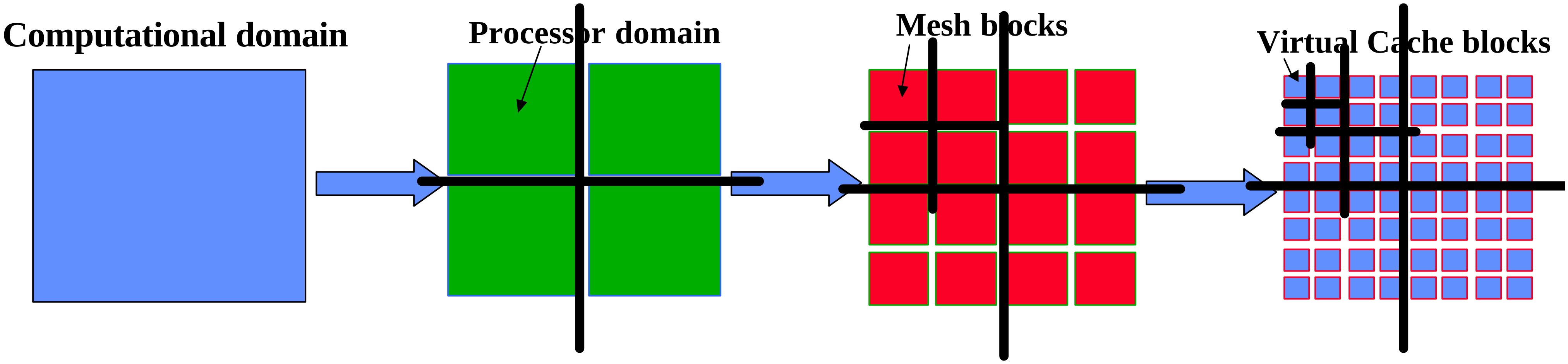




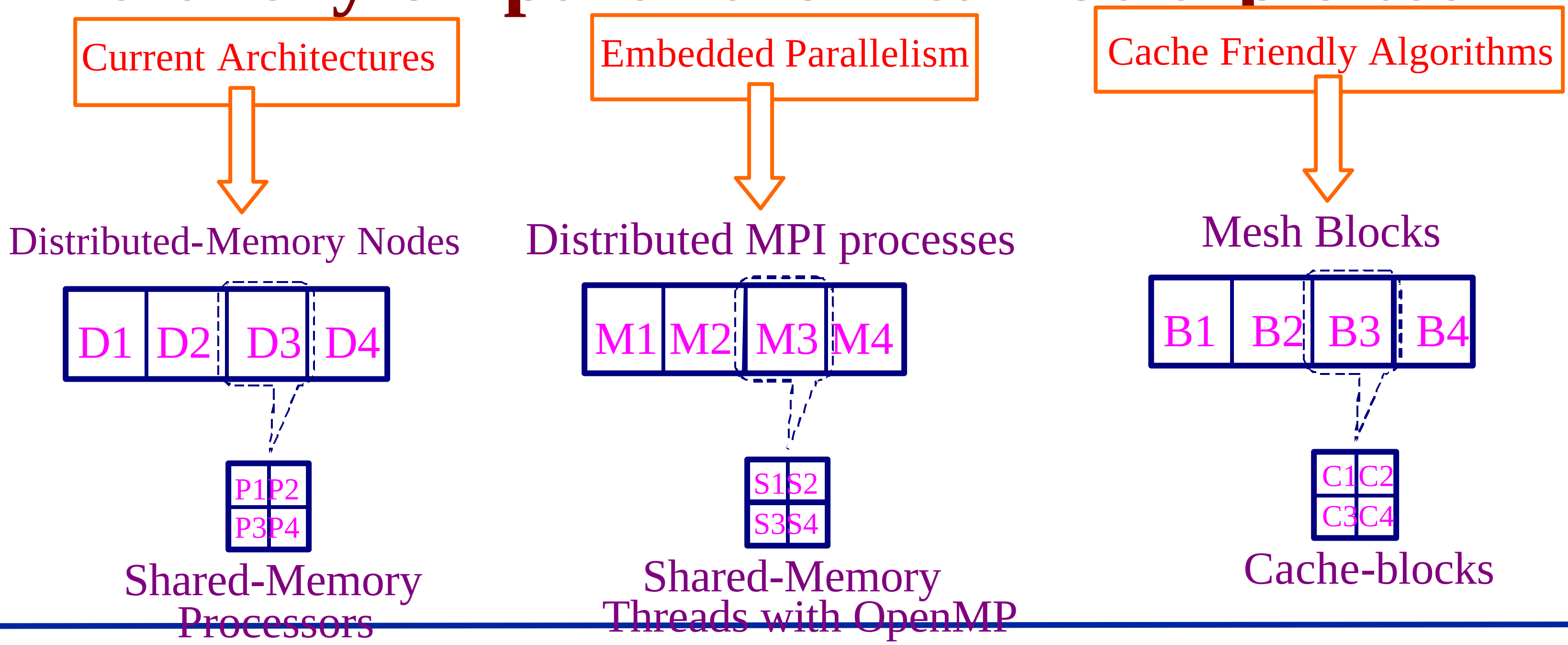
Dependent Technologies

– Single processor performance – solution of linear systems and sparse-matrix vector operations
– Parallel computing paradigms (MPI, OpenMP)
– Parallel I/O, data (MPI-IO/HDF5)
– Distributed visualization and analysis (VisBench)
– GRID technologies: Globus, COG, PSE's……….

GenIDLEST - Parallel Implementation



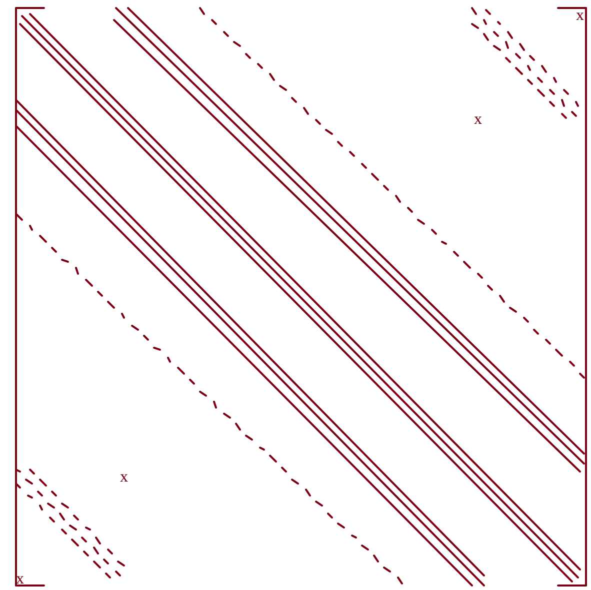
- **Hierarchy of parallelism can be exploited**



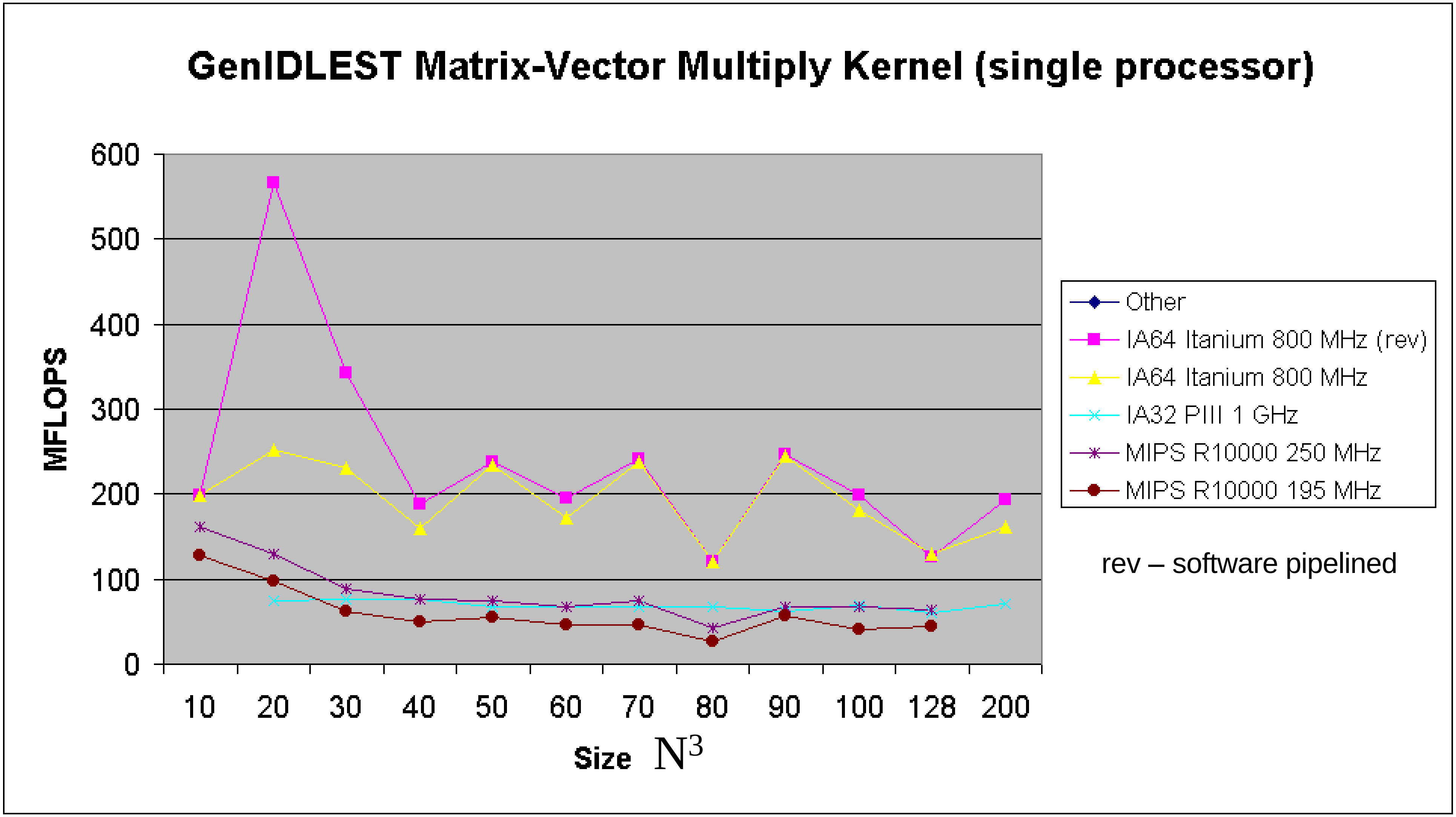
Global System matrix

- Generated in semi-implicit treatment and pressure equation. <u>80-90%</u> of computational work in complex geometries.
- Sparse
  - sparsity pattern depends on B.C.s.
  - Mostly non-symmetric-18 off-diagonal elements in 3-D
- Use CG for SPD systems, and BiCGSTAB, GMRES(m) for nonsymmetric.
- Preconditioners: Additive Schwarz Richardson or SSOR iterations applied to cache blocks.

2D system matrix,
Non-periodic b.c.s
Periodic b.c.s

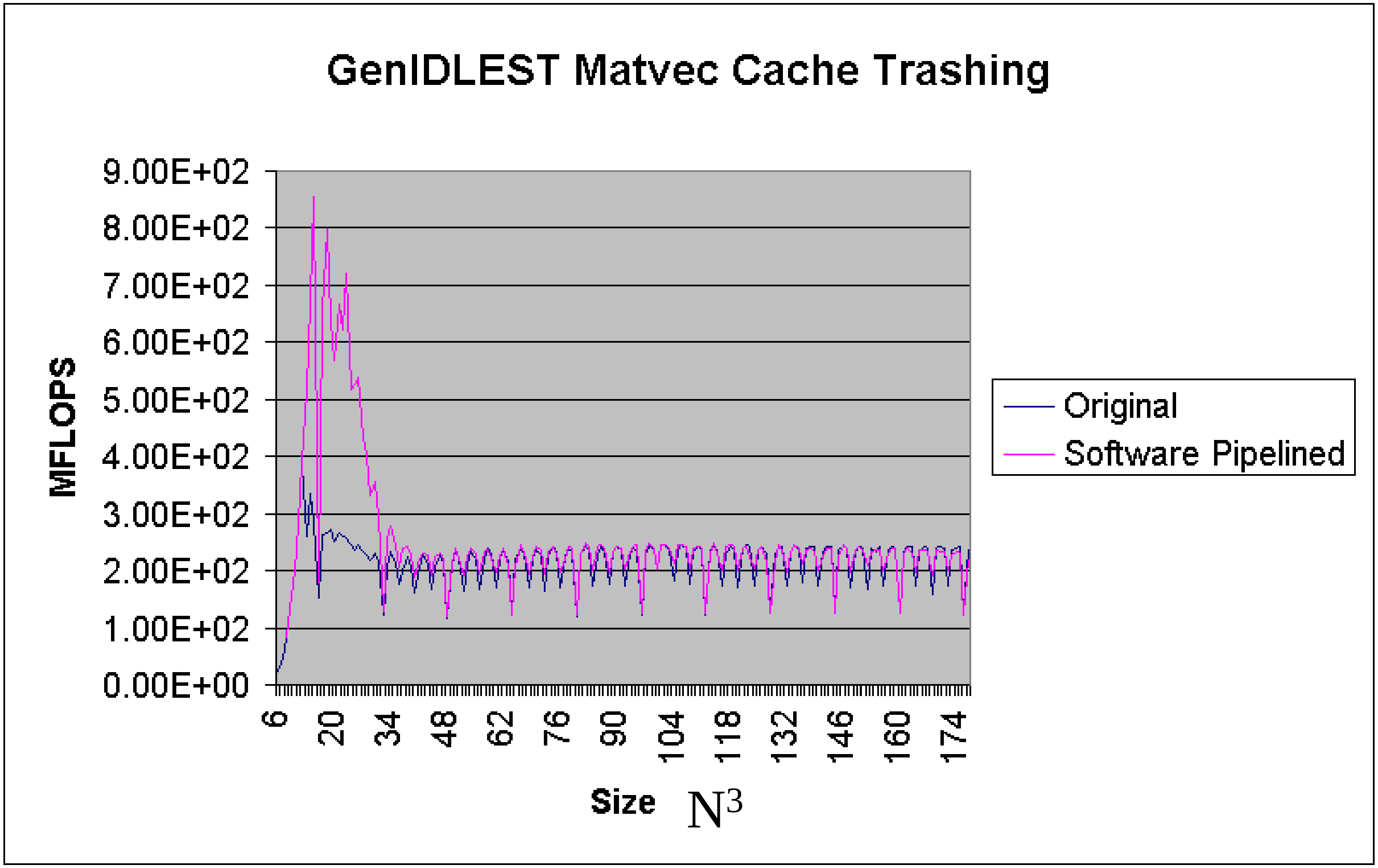


Cross-Platform



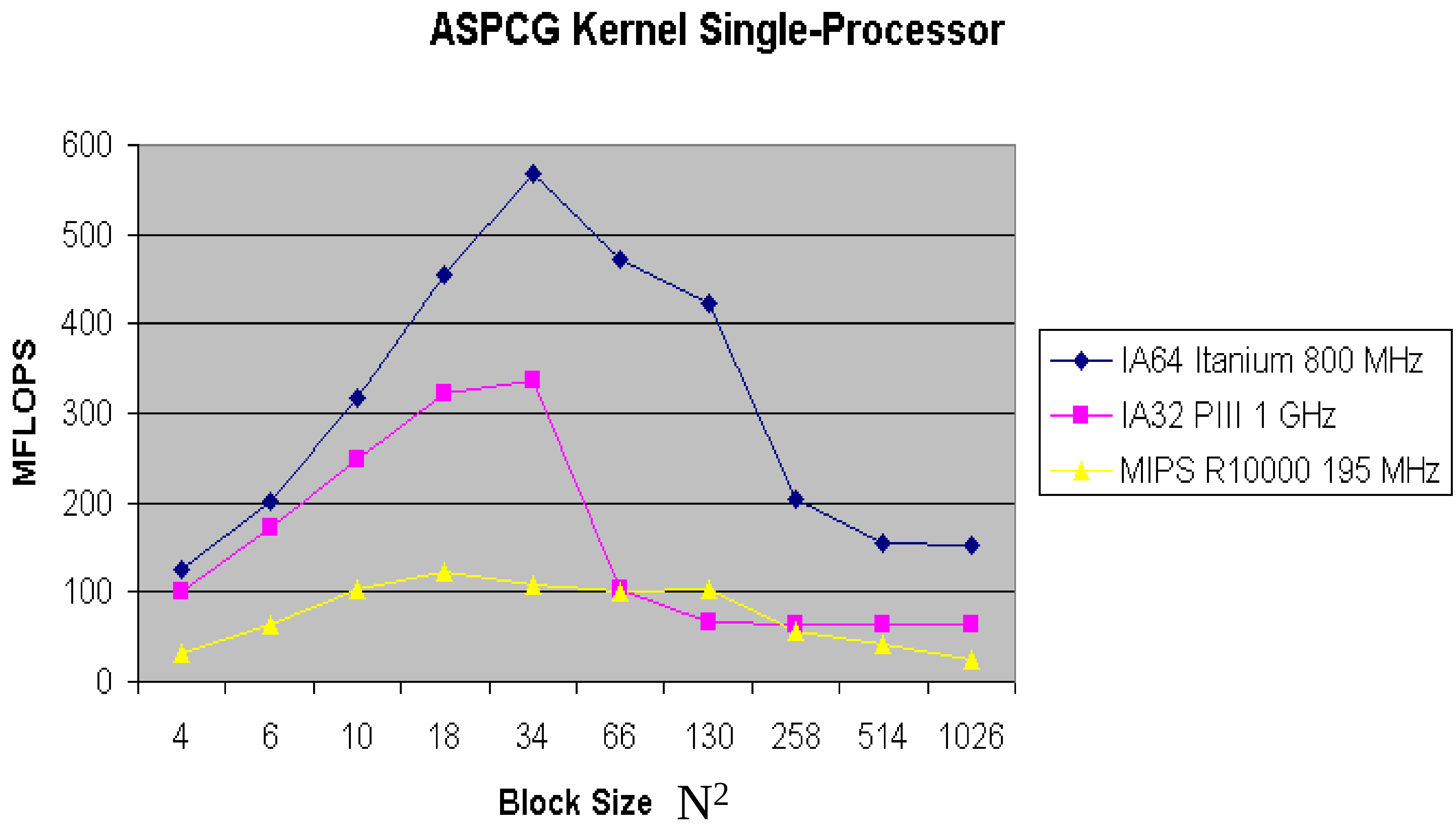
Rick Kufrin, NCSA Performance Engineering

Itanium performance



Rick Kufrin, NCSA Performance Engineering

Linear Solver Performance



Rick Kufrin, NCSA performance engineering

Performance Challenges

- **Better Cache utilization**
  - **Sparse matrix vector multiplies**
  - **Linear solvers**
- **Load Balancing**
  - **Block sizes, physics, processors – static.**
- **General portable implementation of Fast Solvers based on 2-D and 3-D FFTs and linear solves for homogeneous problems.**